

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup> :</b> <b>A61K 47/48</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 99/49897</b> <b>(43) International Publication Date:</b> 7 October 1999 (07.10.99)
<b>(21) International Application Number:</b> PCT/CA99/00260 <b>(22) International Filing Date:</b> 25 March 1999 (25.03.99) <b>(30) Priority Data:</b> 2,233,725 31 March 1998 (31.03.98) CA <b>(71) Applicant:</b> HEMOSOL INC. [CA/CA]; 115 Skyway Avenue, Etobicoke, Ontario M9W 4Z4 (CA). <b>(72) Inventor:</b> ADAMSON, Gordon, W.; 65 Edward Street, Georgetown, Ontario L7G 1V3 (CA). <b>(74) Agents:</b> HIRONS, Robert, G. et al.; Ridout & Maybee, 18th floor, 150 Metcalfe Street, Ottawa, Ontario K2P 1P1 (CA).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>With amended claims and statement.</i>
<b>(54) Title:</b> HEMOGLOBIN-POLYSACCHARIDE CONJUGATES  <b>(57) Abstract</b>  Hemoglobin conjugates useful as hemoglobin-based oxygen carriers are prepared by reacting hemoglobin with oxidatively ring-opened polysaccharides such as hydroxyethyl starch or dextran, and storing the resultant conjugate under conditions which allow it to transform to a lower molecular weight product, after conjugation. The conjugate is then reductively stabilized to form secondary amino bonds between the hemoglobin and the polysaccharide, and formulated as a HBOC.		

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

HEMOGLOBIN-POLYSACCHARIDE CONJUGATESFIELD OF THE INVENTION

5 This invention relates to biocompatible oxygen carriers for administration to patients as a supplement for or a partial replacement for whole blood. More specifically, the invention relates to hemoglobin-based oxygen carriers (HBOCs) for administration to mammals as a blood substitute or supplement, and processes for their  
10 preparation.

BACKGROUND OF THE INVENTION

15 Hemoglobin, as the natural oxygen transporter component of blood, is an obvious candidate to form the basis of a blood substitute, e.g. as an aqueous solution. Extensive scientific work has been done and reported, on attempts to provide a satisfactory hemoglobin solution to act as a blood substitute. The chemical properties of  
20 hemoglobin outside the red blood cells are, however, markedly different from its properties inside the red blood cells, e.g. as regards its oxygen affinity. The need for some form of chemical modification of hemoglobin to render it suitable for use as a blood substitute has long been  
25 recognized and has been quite extensively investigated.

It is well known that hemoglobin comprises a tetramer of four sub-units, namely two  $\alpha$  sub-units each having a globin peptide chain and two  $\beta$  sub-units each  
30 having a globin peptide chain. The tetramer has a molecular weight of approximately 64 kilodaltons, and each sub-unit has approximately the same molecular weight. The tetrameric hemoglobin in dilute aqueous solution readily dissociates into  $\alpha$ - $\beta$  dimers, and even further under some  
35 conditions to  $\alpha$ -sub-unit monomers and  $\beta$ -sub-unit monomers. The dimers and monomers have too low a molecular weight for

retention in the circulatory system of the body, and are filtered by the kidneys for excretion with the urine. This results in an unacceptably short half life of such a product in the body. The benefit of chemical bonding between the sub-units to ensure the maintenance of the tetrameric form ("intramolecular cross-linking") has previously been recognized. Also, the linking together of two or more tetrameric units to form hemoglobin oligomers and polymers of molecular weight greater than 64 kilodaltons ("inter-molecular cross-linking") has also been recognized as desirable in many instances.

Accordingly, one approach to developing HBOCs for clinical use has been intramolecularly cross-linking the hemoglobin units into stabilized tetramers, of molecular weight c. 64 kilodaltons, and optionally oligomerizing these tetramers into oligomers of 2-6 such tetramers, by intermolecular cross-linking. A variety of cross-linking reagents have been proposed for this purpose, including oxidatively ring-opened saccharides such as o-raffinose (U.S. Patent 4,857,636 Hsia and U.S. Patent 5,532,352 Pliura et al., for example), bifunctional imidates such as diethyl-malonimide hydrochloride (U.S. Patent 3,925,344 Muzur), halogenated triazines, divinylsulphones, diisocyanates, glutaraldehyde and other dialdehydes (U.S. Patent 4,001,200 Bonsen et al.), bis-diaspirin esters (U.S. Patent 5,529,719 Tye), bis- and tris-acyl phosphates (U.S. Patent 5,250,665 Kluger et al.) and others.

Another approach to the preparation of HBOCs with appropriate molecular weight for clinical use has been the coupling of hemoglobin to a biocompatible polysaccharide. Such conjugates would have the advantage as compared with cross-linked and oligomerized hemoglobins of requiring lower quantities of hemoglobin per unit of HBOC, and hence

would be more economical to prepare, and have diminished hemoglobin-related toxicities. Conjugation of a colloid to hemoglobin in preparing an HBOC also permits control of fluid properties such as viscosity and colloid osmotic pressure by adjusting the size of the colloid, its degree of modification and the colloid-to-hemoglobin ratio. These same parameters can be used to control the final molecular weight and vascular retention time of the product.

10           U.S. Patent 4,064,118 Wong proposes the preparation of a blood substitute or blood extender by chemically coupling hemoglobin with a polysaccharide material selected from dextran and hydroxyethyl starch of molecular weight from about 5 kDa - 2,000 kDa. Only the use of dextran is exemplified in this patent, however.

Baldwin et al. "Tetrahedron" 37, pp 1723-1726 (1981) "Synthesis of Polymer-Bound Hemoglobin Samples" describe the chemical modification of dextran and hydroxyethyl starch (HES) to form aldehyde-substituted polymers, and their subsequent reaction with hemoglobin, to form soluble, polymer-bound hemoglobin. Whilst the products so formed were capable of binding oxygen, they are reported as unsuitable for use as blood substitutes, since their oxygen-binding curves were considerably left-shifted, indicating that they have too high an oxygen affinity ( $P_{50}$  too low).

#### SUMMARY OF THE INVENTION

30

It is an object of the present invention to provide a novel HBOC.

It is a further object of the invention to

provide a novel polysaccharide-hemoglobin conjugate useful as an HBOC.

5 It is a further object to provide a process for preparing a novel polysaccharide-hemoglobin conjugate useful as an HBOC.

10 In the process of the present invention, a polysaccharide is used, in oxidatively ring-opened form. In this oxidative form, at least a portion of the saccharide monomeric units are oxidized to present aldehyde groups. The oxidized polysaccharide so formed is then reacted with extracellular hemoglobin, so that the hemoglobin, through primary amine groups of the globin chains reacting with the aldehyde groups of the oxidized polysaccharide, covalently binds to the polysaccharide through Schiff base linkages. 15 Initially and very rapidly there is formed a product which includes species of very high molecular weight, of the order of 500 kDa or higher, in substantial amounts and a wide molecular weight distribution (128->500 kDa). 20

On maintaining this product under appropriate conditions, in aqueous solution, it can be transformed, to a controlled extent, over a relatively short period of time 25 (e.g. 4-48 hours depending upon the conditions) to a much lower molecular weight product (90-200 kDa) with a much narrower molecular weight distribution. This product, after chemical reduction to reduce the Schiff base linkages between the hemoglobin and the polysaccharide to secondary amine bonds, turns out to have properties such as oxygen 30 affinity in the range  $P_{50} = 4$  to 50 mmHg at 37°C, depending on the ligand state of the hemoglobin at the time of conjugation, which makes it eminently suitable as a candidate for a hemoglobin based oxygen carrier for

clinical use in mammals. The degree of transformation can be controlled by the timing of the application of the reduction step. Moreover, the resulting product contains no detectable unreacted hemoglobin which, if present, would  
5 dissociate to give  $\alpha\beta$ -dimers suspected of causing renal injury, and no detectable amounts of excessively high molecular weight products (over about 500-600 kDa).

Thus according to the first aspect of the present  
10 invention, there is provided a polysaccharide-hemoglobin conjugate useful as a hemoglobin based oxygen carrier and having an oxygen affinity, expressed as partial pressure of oxygen environment required to maintain 50% oxygen  
15 saturation,  $P_{50}$  of = 4-50 mmHg, at 37°C, and containing no detectable residual unbound hemoglobin and no detectable residual amounts of components of molecular weight higher than about 500 kDa, said conjugate having been prepared by reacting hemoglobin with oxidized polysaccharide to form a  
20 high molecular weight conjugate complex, and allowing the high molecular weight conjugate complex to degrade by storage in solution at a suitable pH value, readily determinable by simple, routine experiments, and at a temperature from 2°C to about 45°C to form said  
25 polysaccharide-hemoglobin conjugate.

A further aspect of the invention provides a polysaccharide-hemoglobin conjugate useful as an oxygen transporter, comprising hemoglobin covalently linked through secondary amine linkages from amino groups on the  
30 hemoglobin to residues of aldehyde groups on the polysaccharide, said aldehyde groups having been formed by oxidative ring-opening of saccharide monomeric units of the polysaccharide.

35 According to another aspect, the present

invention provides a process of preparing a hemoglobin based oxygen carrier which comprises reacting an oxidatively ring-opened polysaccharide carrying aldehyde groups with hemoglobin to form a Schiff based-linked conjugate thereof, allowing the conjugate to stand under conditions which effect molecular weight reduction of the conjugate, stabilizing the conjugate by reduction of the Schiff base linkages to stable, secondary amine linkages, and recovering a solution of the polysaccharide-hemoglobin conjugate so formed which has no detectable unbound hemoglobin residue and no detectable product residue of molecular weight greater than about 500-600 kDa.

#### BRIEF REFERENCE TO THE DRAWINGS

15

Figures 1, 2 and 3 are sets of chromatograms of products of Example 2 below;

Figure 4 is a size exclusion chromatographic analysis of products of Example 3 below;

20

Figure 5 is a similar set of chromatograms of products of Example 6 below; and

25

Figure 6 is a similar set of chromatograms of products of Example 7 below.

Figures 7 and 8 are similar sets of chromatograms of products of Example 8 below.

30

Figure 9 is a similar set of chromatograms illustrating the results of Example 10 below.

Figures 10, 11 and 12 are similar sets of chromatograms from products of Example 11 below.

35



DESCRIPTION OF THE PREFERRED EMBODIMENTS

Apparent molecular weights described in this application are derived by comparison with size exclusion chromatography elution times of o-raffinose polymerized hemoglobin (polyOR-Hb) standards of known molecular weight.

Since hemoglobin-colloid conjugates are suspected to contain significant amounts of trapped water in the extended colloid chain component, the actual molecular weight of the conjugate including only molecules covalently attached to the hemoglobin is less than the apparent molecular weight. However, it is the apparent molecular weight, or excluded volume, that will dictate the in vivo retention time of the conjugate, and so molecular weight as described above will be used to describe the conjugates reported here.

The hemoglobin for use in the process of the present invention is preferably human hemoglobin, derived from red blood cells. However, the invention is applicable also to other types of hemoglobin to form the basis of a blood substitute, such as animal hemoglobins especially bovine hemoglobin, and porcine hemoglobin and the like, and hemoglobin derived from cell culture. Human hemoglobin is currently the preferred choice, to form the basis of a blood substitute for administration to human patients.

The hemoglobin can be recovered and prepared for use in the present invention according to standard, known techniques. Thus, red blood cells are lysed, and cellular debris and stroma are removed therefrom by standard techniques of centrifugation, filtration and the like. Preferably, a solution of hemoglobin with a concentration of 2-20% by weight of hemoglobin is used, to yield a

product having the most desirable composition and combination of properties. Final purification can suitably take place chromatographically. The displacement chromatography process described in U.S. Patent 5,439,591  
5 Pliura et al. is beneficially used.

Hemoglobin can naturally exist in the tight (T) conformation as normally assumed by deoxyhemoglobin, or in the relaxed (R) conformation as normally assumed by  
10 oxyhemoglobin or carbon monoxyhemoglobin. The oxygen binding characteristics of hemoglobin in the T state are the more desirable characteristics, since the oxygen affinity of hemoglobin in this conformation allows efficient oxygen binding in the lung vasculature and oxygen  
15 offloading in the peripheral tissues. It is accordingly preferred to use deoxyhemoglobin in the process of the invention. After conjugation to the hydroxyethyl starch (HES) with or without prior cross-linking, the deoxy-hemoglobin retains oxygen binding characteristics of the T-  
20 configuration. If, however, one chooses for any reason to start with R-configuration hemoglobin, the preferred process according to the invention stabilizes the hemoglobin into the R-configuration throughout. Mixtures of R- and T-state hemoglobins can be reacted with the HES to  
25 obtain products with oxygen binding properties intermediate between those of the R- and T-state configurations.

Deoxygenation of hemoglobin to form deoxyhemoglobin is preferably conducted by subjecting the  
30 hemoglobin solution to treatment with a non-oxygenating gas such as nitrogen, according to known techniques. It is preferred to continue the treatment with a stream of nitrogen, followed by appropriate degassing, for sufficiently long periods of time to effect complete

conversion to deoxyhemoglobin in this manner.

Polysaccharides useful in the present invention include those of established biocompatibility, and having  
5 saccharide monomeric units capable of oxidative ring opening to form reactive aldehyde groups. They include starches and starch derivatives, dextran, inulin and the like. Preferred among the polysaccharides for use in the present invention are hydroxyethyl starch and dextran, with  
10 HES being most preferred.

The hemoglobin can be reacted with the oxidized hydroxyethyl starch in its native, non-cross-linked form, or in its cross-linked, 64 kDa tetrameric stabilized form,  
15 or in its cross-linked and oligomerized form comprising 64 - <500 kDa adducts. When used in its cross-linked form, the preferred cross-linking reagent for preparing cross-linked and cross-linked-oligomerized hemoglobin is a polyaldehyde derived from the oxidative ring-opening of an  
20 oligosaccharide such as raffinose (i.e. o-raffinose). A suitable process for preparation of o-raffinose and for its reaction with hemoglobin is described in the above-mentioned U.S. Patent 5,532,352 Pliura et al., the disclosure of which is incorporated herein by reference.  
25 Whilst o-raffinose is the preferred cross-linking reagent for use in this embodiment of the invention, it is by no means limited thereto. Any of the other known Hb cross-linking reagents, such as those mentioned previously, for example trimesoylmethyl phosphate (TMMP) described in U.S.  
30 Patent 5,250,665 Kluger et al. can be satisfactorily used.

The hydroxyethyl starch starting material for use in preferred embodiments of the present invention suitably has a molecular weight of from about 70 to about  
35 1000 kDa. It is commercially available, in various types

and varieties. The type and variety for use in the present invention is not critical. Substantially any of the currently commercially available varieties of HES can be used as the starting material, provided that they have a  
5 molecular weight approximately as set out above. Those with a substitution ratio (i.e. number of hydroxyethyl groups to glucose units) of from about 0.5 to 0.7 are particularly suitable.

10 To prepare the HES for use in the present invention, it is oxidized, so as to create thereon substantial numbers of aldehyde groups. This can be accomplished by a variety of oxidation processes, the preferred one being reaction with a periodate (sodium or  
15 potassium). This reaction can take place in aqueous solution at low temperature, e.g. 0-5°C, using an appropriate quantity of sodium periodate, chosen according to the desired degree of oxidation. The reaction is complete in about 1-4 hours. Ultrafiltration or dialysis  
20 can be used to remove undesirable low molecular weight salts and HES components, thereby offering a means of controlling the molecular weight range of oxidized HES to be conjugated to the Hb. The oxidized HES can be used directly or is suitably recovered, e.g. by lyophilization,  
25 and redissolved in water for conjugation to the hemoglobin.

The conjugation reaction suitably takes place in aqueous solution. The hemoglobin may optionally be cross-linked Hb and/or oligomerized Hb. It may be liganded e.g.  
30 with carbon monoxide, (CO-Hb). Lower  $P_{50}$  values in the final products are obtained with CO-Hb, higher values with deoxy Hb. Molar ratios of Hb:oxidized HES can range anywhere from about 0.25:1 to 5:1, but are preferably in the 0.5:1-3:1 approximate range. The reaction best takes place at  
35 alkaline pH, e.g. in the range 7.5-9.0, and at room

temperatures.

The reaction product formed initially, e.g. after about 1 hour is found on analysis to have a very high molecular weight, with components of molecular weight well in excess of 500 kDa, no matter what the molecular weight of the starting polysaccharide may have been. This initial product also contains a broad range of molecular weight products. One can effect a controlled reduction in the molecular weight of the product, to a product containing no components of molecular weight higher than about 500,000, and to a product of narrow molecular weight distribution (e.g containing predominantly species of 100 - 200 kDa molecular weight), by maintaining the product in aqueous solution, preferably in the approximate pH range 7.2-10, and at or close to room temperature (15°C-30°C), for a period of time up to about 48 hours. There is very little, if any, residual 32 kDa species. The amount of 32 kDa species is so small that no special steps for its removal are necessary.

The conjugate so formed must be stabilized by reducing the (reversible) Schiff base linkages between the Hb and the HES to stable secondary amine linkages and by reducing any unreacted aldehyde groups. The reduction can be accomplished in a single stage, in which the Schiff base linkages and the aldehyde groups are reduced in a single stage, or in two separate stages. Powerful reducing agents will be effective in one stage, less powerful reducing agents requiring a two-stage process.

This step of reduction is preferably used as the means of control of the molecular weight and molecular weight distribution of the final product, by appropriate timing thereof. Once the reduction has been completed, the

product is stabilized and no further changes in molecular weight or molecular weight distribution of any significance will occur on storage. Accordingly, analysis of samples of reaction product at intervals allows timing of the  
5 reduction step to stabilize the product at the chosen characteristics.

Borane dimethylamine is the preferred choice as the reducing agent. This is powerful enough to accomplish  
10 both reduction reactions in a single stage. Other water soluble borane lower alkyl amine reducing agents including but not limited to borane-tert-butylamine, borane-ammonia; borane-dimethylamine; borane-trimethylamine; borane triethylamine; and pyridine borane can also be used. Other  
15 useful reducing agents are sodium cyanoborohydride and sodium borohydride.

Reduction of the Schiff bases formed during the conjugation, and reduction of any residual unreacted  
20 aldehyde groups, most suitably takes place in aqueous solution at a temperature range of 2-25°C, for a period of time from 10-36 hours, preferably 24 hours. The reaction mixture is suitably buffered to pH 7-10, preferably to 8.0-9.5. The molar ratio of reducing agent to the sum of imine  
25 and aldehyde groups is in the range 1:1 to 5:1, preferably 1.5:1 to 3.5:1 based on the stoichiometry of reducing agent to aldehyde groups added to initiate cross-linking.

It is preferred to use a final step of  
30 diafiltration, to remove residual low molecular weight products such as starch degradation residues, dimethylamino borane residues, salts, buffer residues, etc. Then the product can be mixed with a suitable excipient, to form an HBOC.

The conjugate so prepared exhibits eminently suitable properties for use as the basis of an HBOC. It exhibits low oxygen affinity ( $P_{50} = 20-50$  mmHg) along with a narrow molecular weight distribution of product (MWD 100-  
5 200 kDa), with no detectable product of m. wt. 32 kDa under conditions which promote dissociation to  $\alpha\beta$ -dimers, or m. wt. above about 500 kDa.

For storage prior to use, it is suitable to  
10 remove all oxygen from the product to prevent autoxidation. Deoxygenated product can be stored under conditions which prevent introduction of oxygen, either frozen or at higher temperatures. Oxygen can be introduced prior to  
15 administration, or the product can be allowed to acquire oxygen in vivo. The carbonmonoxy form can be stored in a similar manner and oxygenated prior to use. The product can be stored frozen in the oxygenated form, or at higher temperatures until the degree of autoxidation is deemed unacceptable.

20

The invention is further described for illustrative purposes only, in the following specific, non-limiting examples.

25 EXAMPLE 1 - PREPARATION OF OXIDIZED HYDROXYETHYL STARCH

9.0 g hydroxyethyl starch with weight average molecular weight (MW) of 450 kDa, having a degree of hydroxyethyl substitution of 0.7, was dissolved in 90 mL  
30 water. 0.49, 0.98 and 1.96 g sodium meta-periodate, representing approximately 0.3, 0.6 and 1.2 eq, respectively, of periodate per mol of vicinal diol present in the HES, were added to separate 30 mL aliquots of this solution. These amounts are sufficient to provide  
35 approximately 30%, 60% and 100% oxidation of available diol

groups. After 4 hours reaction in the dark at 4°C, the solutions were dialyzed extensively against chilled water using a 15 kDa molecular weight cutoff membrane. Final retentates were lyophilized to white powders and stored at room temperature. Alternatively, the dialyzed oxidized HES solution could be used directly for conjugation of Hb. HES with MW of 200 kDa and substitution of 0.5 was oxidized and prepared in a similar manner. Oxidized HES was also prepared by direct oxidation of HES formulated in 0.9% NaCl. Measurements of periodate consumption and final aldehyde content indicated that the range of periodate used resulted in partial to complete oxidation of all available diol groups, and that the degree of oxidation was readily controlled by varying the amount of periodate used.

EXAMPLE 2 - PREPARATION OF CONJUGATES WITH VARIOUS OXIDIZED HES and CO-HEMOGLOBIN

The reaction of CO-Hb with various relative ratios of oxidized HES (HES-CHO) was studied. Periodate equivalents for oxidation were calculated based on the expected vicinal diol content of the HES. In one case, 0.54 g oxidized 450 kDa HES, prepared using 1.2 eq periodate as described in example 1, was dissolved in 3.0 mL 100 mM HEPES buffer pH 8.1. This HES-CHO solution was added to carbonmonoxylated hemoglobin (COHb, 200 mg/mL in water) in the following ratios: 0.76 mL HES-CHO:0.041 mL COHb, 0.73:0.078, and 0.61:0.195, giving final Hb concentrations of approximately 10, 20 and 50 mg/mL, respectively. The reactions were allowed to proceed at 22-25°C, at pH 8, and samples were withdrawn at various times for MW determination using a Pharmacia Superdex 200 column (1x30 cm) eluted with 0.5 M MgCl<sub>2</sub> + 25 mM Tris pH 7.2 at 0.4 mL/min. At all three HES:COHb ratios, Hb was completely modified in the first several hours to give



species having elution times comparable to polyHb controls with MW greater than 128 kDa and ranging to above the exclusion limit of the column (>500 kDa polyHb). Figure 1 of the accompanying drawings shows the chromatogram derived from the 0.5:1 Hb:HES product (50 mg Hb/ml), taken at various times and compared with (bottom curve) the poly Hb control. The dashed vertical line represents the elution time of 32 kDa unmodified  $\alpha$ - $\beta$  dimer. The absorbance at 414 nm characteristic of hemoglobin is tracked in the eluting fractions. During the next 30 hours, the elution times of the product decreased to give species having elution times comparable to polyHb controls with MW of 128 kDa, with no unmodified Hb detectable and no species above the exclusion limit of the column. The pattern of MW evolution and final product MW ranges were similar at all three HES:Hb ratios, as with HES oxidized with 0.6 eq periodate. Conjugates prepared using HES oxidized with 0.3 eq periodate per diol typically contained significant material co-eluting with unmodified  $\alpha$ - $\beta$  dimer. Higher levels of oxidation were therefore preferable for generating conjugate free of unmodified dimer.

The average MW of conjugates formed during the first several hours was lower when less Hb was used. Similar reactions and results were obtained using oxidized 200 kDa HES as described in Example 1. Average MW of final products were higher when 450 kDa HES was used in comparison to 200 kDa HES. Fig. 2 of the accompanying drawings shows chromatograms of the final products of Hb+HES-CHO for HES 200/0.5 (broken lines) and HES 450/0.7 (solid lines), at different degrees of oxidation as indicated, all at 1:1 Hb:HES-CHO ratios.

Hb-HES conjugates obtained using periodate

oxidized 70 kDa HES (0.3, 0.6 and 1.2 eq. periodate vs. calculated diol) also formed higher MW species during the early phase of conjugation, followed by transformation to lower MW (Figure 3). Average MW of early phase conjugates, as well as the time required to convert to lower MW species, was dependent on the degree of oxidation of the HES 70. After 48 hours conjugation, some material coeluting with the 32 kDa unmodified Hb component of the polyOR-Hb control remained in the conjugate derived from the lowest degree of HES oxidation (0.3 eq periodate per calculated diol). Significant material eluting at the analytical column exclusion limit remained after 48 hour in the reaction using the most highly oxidized HES 70 (1.2 eq periodate per calculated diol). Product free of unmodified hemoglobin and material eluting at the column exclusion limit was obtained within 48 hours of reaction with HES oxidized by 0.6 eq. periodate per calculated diol.

Example 3: Simultaneous large scale preparation of high and low MW Hb-HES conjugates

Two Hb-HES conjugates of different MW were prepared from a single reaction, in which a portion of the early conjugation product having high MW was isolated and stabilized, allowing the remaining conjugation product to undergo transformation to a lower MW product before stabilization. A comparison of physical and in vivo properties of the two products was made so that the beneficial properties of one over the other could be demonstrated.

944 g HES (200 kDa, degree of substitution = 0.5) was dissolved in 8 L WFI, cooled to 4°C, then 370 g NaIO<sub>4</sub> added and the mixture stirred in the dark for 5.3 hours.

All  $\text{NaIO}_4$  dissolved in less than 1 hour. The mixture was filtered (0.2  $\mu\text{m}$ ) then diafiltered against 12 volumes room temperature WFI (water for injection) using a 30 kDa regenerated cellulose membrane. It was then deoxygenated by contact with  $\text{N}_2$  through a hollow fibre membrane. Lyophilized samples indicated a final concentration of 128 mg HES-CHO/mL. 1.2 L of COHb (23.2 g/dL in WFI) was combined with 2.0 L 200 mM HEPES pH 8.1 buffer, then oxygenated and deoxygenated by contact with  $\text{O}_2$  then  $\text{N}_2$  through a hollow fibre membrane. 4.5 kg of the HES-CHO solution (128 g/L) was combined with the deoxygenated Hb (3.2 L at 9.0 g/dL) and the mixture maintained under deoxy conditions. The MWD of the conjugates forming was monitored by size exclusion chromatography.

After 3 hours conjugation, half of the reaction volume was transferred under  $\text{N}_2$  to a separate vessel and 56 mL 3 M NaOAc and 196 g DMB, dissolved in 1.7 L WFI, were added. The final DMB:initial aldehyde ratio was 1.5:1. The mixture was kept under  $\text{N}_2$  at ambient temperature for 23 hours before CO charging and diafiltration. At 29 hours after initiation of the Hb-HES conjugation reaction, the other half of the mixture was treated similarly with NaOAc and DMB for 17.5 hours. Both DMB-reduced reactions were then CO charged and diafiltered vs. WFI then Ringer's lactate (approximately 10 volumes for each solution). The pH was adjusted to 7.5-7.6 with 0.1 N HCl. Both solutions were concentrated such that colloid osmotic pressure was 80-100 mm Hg. Products were oxygenated and approximately three-quarters removed for sterile filtration and packaging in the oxy form. The remaining amounts of each were deoxygenated and packaged in the deoxy form. Oxygenated products were stored at  $-80^\circ\text{C}$ , deoxygenated products at  $4^\circ\text{C}$ . The higher MW product, obtained by reduction of early stage conjugation product, is hereafter referred to as HIMW

HES-Hb. The lower MW product, obtained by reduction of the late stage conjugation product, is hereafter referred to as LOMW HES-Hb. MW distributions assessed by size exclusion chromatography are shown in Figure 4. MW distribution did not change over four months storage at either 4 or -80°C.

The colloid osmotic pressure (COP) of HIMW HES-Hb was consistently higher than LOMW HES-Hb at the various concentrations tested for both products (Table 1). Viscosities were 8.9 and 3.0 cSt at 6.5 and 9.0 g Hb/dL for HIMW HES-Hb and LOMW HES-Hb, respectively. HIMW HES-Hb, which is comparable in MW distribution to HES- and dextran-Hb conjugates prepared by others, therefore has colloidal properties which would be expected to result in a greater change in blood fluid and rheological properties than LOMW HES-Hb. The deleterious effects of higher MW HES plasma components on rheological factors such as viscosity and erythrocyte aggregation, and on blood clotting, have been described (Treib et al., Thrombosis and Haemostasis 74:1452-6 (1995)).

Table 1: Concentration dependence of COP for HIMW and LOMW HES-Hb

HIMW HES-Hb		LOMW HES-Hb	
Conc (g Hb/dL)	COP (mm Hg)	Conc (g Hb/dL)	COP (mm Hg)
6.5	103.5	9.0	85.4
4.2	35.7	6.1	36.6
2.1	8.6	3.1	11.3

EXAMPLE 4 - EFFECT OF LIGAND STATE ON FINAL  $P_{50}$

COHb (55 mg/mL in water) was oxygenated and deoxygenated by exposure to oxygen then nitrogen,

respectively. 200 kDa HES was oxidized using 0.6 eq periodate as described in Example 1, and made up to 60 mg/mL in 100 mM HEPES pH 8.1, and degassed and purged with nitrogen. 2.5 mL of this oxidized HES solution was added to 0.8 mL of the deoxygenated Hb solution, providing 1 eq Hb per mol of initial unoxidized 200 kDa HES. After 48 hours at 22-25°C under nitrogen, the reaction mixture was made 0.3 M in sodium acetate, then 3 eq dimethylamine borane per mole of initial aldehyde were added. After 24 hours, the solution was charged with CO gas, and exhaustively dialyzed against lactated Ringer's solution. A similar procedure was conducted in which COHb, without removal of the CO ligand, was reacted with 200 kDa HES oxidized by 0.6 eq periodate. Oxygen binding properties were measured for both products using a Hemox-Analyzer (TCS Instruments, Southhampton, Pennsylvania, U.S.A.) at 37°C. Conjugation of deoxygenated Hb resulted in a final  $P_{50}$  of 26 mm Hg. Conjugation of COHb resulted in a final  $P_{50}$  of 4 mm Hg. Both products were non-cooperative.

#### EXAMPLE 5 - USE OF CROSS-LINKED HEMOGLOBIN

200 kDa HES was oxidized by 0.3 eq and 0.6 eq periodate in separate reactions as described in Example 1, and made up to 125 mg/mL in 270 mM sodium bicarbonate pH 8.1. 3.0 mL of each oxidized HES solution was added to separate 1.0 mL aliquots of trimesoyl tris(methyl phosphate) (TMMP)-cross-linked Hb (64 kDa cross-linked Hb, U.S. Patent 5,250,665 Kluger et al., 125 mg/mL in water), and likewise to 1.0 mL aliquots of o-raffinose polymerized Hb (64 - <500 kDa Hb polymers, U.S. Patent 5,532,352 Pliura et al., 117 mg/mL), for a total of four reactions, in all cases providing 1 eq Hb per mol of initial unoxidized 200 kDa HES. Both hemoglobin products were in the CO form. After 30 hours reaction at 22-25°C under CO gas, sodium

acetate was added to a final concentration of 0.3 M. 3 eq dimethylamine borane per mol of initial aldehyde was then added. After 24 hours, the reactions were dialyzed (10 kDa MWCO) against water then lactated Ringer's solution at pH 7.4. Oxygen binding properties were then recorded using a Hemox-Analyzer at 37°C.

MW distributions of all Hbs were shifted to higher values. With Hb and TMMP-cross-linked-Hb, it was possible to modify all starting Hb and there was no detectable void volume material (Superose 12, dissociating conditions) within 48 hr. PolyOR-Hb conjugates contained significant void volume material.  $P_{50}$ s (37°) were: HES + CO-TM-Hb, 5-7 mmHg; HES + CO-polyOR-Hb, 5-7 mmHg. All products were non-cooperative.

#### EXAMPLE 6 - VARIATION IN REACTION TIME AND TEMPERATURE

The effect of shorter reaction times and lower temperature (12 vs. 22°C) on Hb-HES MWD was studied on a small scale. Oxidized forms of 200 kDa and 450 kDa HES were used.

Deoxygenated Hb was used. COHb (50 mg/mL in 75 mM HEPES buffer pH 8.1) was oxygenated and deoxygenated by exposure to oxygen then nitrogen, respectively. Oxidized HES, derived from either 200 or 450 kDa HES using 0.6 or 1.2 eq periodate per mol of vicinal diol, respectively, was dissolved in 100 mM HEPES buffer pH 8.1 to a final concentration of 60 mg/mL, and the solutions were then degassed and purged with nitrogen. 0.253 mL of Hb was combined with 1.6 mL of oxidized 200 kDa HES solution, and 0.498 mL of Hb was combined with 1.4 mL of oxidized 450 kDa HES solution, in both cases providing 1 eq Hb per mol of initial unoxidized 200 kDa or 450 kDa HES. These solutions

were allowed to react at 22°C under nitrogen, and identical solutions were prepared and allowed to react at 12°C. MWD were determined at various time points as described in Example 2. Chromatographic profiles are shown in Figure 5.

5

Final MWD was narrower at 22°C for both oxidized HES's, and at longer reaction times for both temperatures. Average MW of the 450 kDa HES product (solid lines) was greater than for the 200 kDa derivative (dashed lines), with the MW difference being larger at the lower temperature. Reactions proceeded more slowly at lower temperature, resulting in greater average MW and wider molecular weight range compared to similar reaction times at higher temperature.

10

#### EXAMPLE 7 - SCALE-UP

Conjugation of oxidized HES to deoxy Hb was scaled up for in vivo evaluation.

15

COHb was made up to 125 mg/mL in 100 mM HEPES buffer pH 8.1 and rendered ligand-free by contact with oxygen then nitrogen using a hollow fibre gas exchanger. 47 g of oxidized 200 kDa HES, prepared as in Example 1 using 0.6 eq periodate, was dissolved in 280 mL 100 mM HEPES buffer pH 8.1, then degassed and purged with nitrogen. The oxidized HES solution was then added to the deoxyHb and maintained under nitrogen at 22-25°C with periodic measurement of MWD. Within 16 hours, all Hb was modified and no product eluted at the exclusion limit of the column (Fig. 6). The lowermost curve, presented for comparison purposes, is derived from Hb cross-linked with oxidatively ring-opened raffinose (polyOR-Hb). The reaction was made 0.4 M in sodium acetate, and 36 g dimethylamine borane was added, representing approximately 3 eq borane

20

25

30

35

per mole of initial aldehyde. After 21 hours, the reaction mixture was oxygenated, diafiltered (10 kDa MWCO) against lactated Ringer's solution and adjusted to pH 7.4. The product had a P50 (37°C) = 26 mmHg and was non-cooperative.

5 Low angle laser light scattering analysis of size exclusion chromatographic effluent indicated a MW of 90-210 kDa. No free aldehyde was detectable.

Analysis of in vivo half-life shows that the Hb-  
10 HES product is retained for extensive periods.  
A volume of the product, adjusted to 3.0 g Hb/dL in lactated Ringer's solution, equivalent to 10% of total blood volume was infused into conscious rats and the vascular retention time determined. The half-life was 6.0  
15 hours, compared to 5.1 hours determined for an equivalent volume of polyOR-Hb, adjusted to 10.0 g/dL in lactated Ringer's solution.

20 Example 8: Conjugation of Hb with oxidized dextran and transformation to lower MW

Two oxidized dextrans were prepared using either 0.45 or 1.36 eq periodate per diol (2 diols per dextran chain monomer). Solutions of 2.0 g dextran (260 kDa)  
25 dissolved in 40 mL 4°C water were treated with either 2.39 or 7.18 g sodium periodate (0.45 and 1.36 eq, respectively). After 4 hours stirring in the dark at 4°C, the solutions were dialyzed (10 kDa MW cutoff) and lyophilized to white powders. 50 mg of oxidized dextran in  
30 1 mL 80 mM HEPES pH 8.1 buffer was combined with 0.062 mL COHb (200 mg/mL) and the conjugation reaction was monitored by size exclusion chromatography under dissociating, non-denaturing conditions (0.5 M MgCl<sub>2</sub> + 25 mM Tris pH 7.4). The results are shown on Fig. 7, for the product  
35 where dextran was oxidized using 0.45 equivalents of



periodate per diol, and on Fig. 8 for the 1.36 equivalents periodate per diol experiment. Both reactions showed initial formation of high MW species eluting largely in the column exclusion volume. Conjugate derived from the highly oxidized dextran was more rapidly transformed to low MW species than when using less oxidized dextran. The similarity in MW profiles for the polyOR-Hb control and the highly oxidized dextran conjugate, with the exception of overall higher MW for the latter, suggests the conjugate is made up of polymerized, cross-linked Hb species which are decorated with polysaccharide fragments. This configuration is also suggested for oxidized HES conjugates obtained under some conditions (Figure 3).

15 Example 9: Plasma half-life of LOMW and HIMW Hb-HES conjugates

Male Sprague Dawley rats were acclimatized for one week with free access to food and tap water. On the day of the experiment, rats were anesthetized with Ketaset (ketamin hydrochloride, 60 mg/kg, i.m.) and Atravet (acepromazine maleate, 2.0 mg/kg, i.m.). The right femoral artery and vein were cannulated using a 2.5-3.5 cm PE10 tubing connected to a PE50 tubing filled with heparin-saline solution (50 USP units heparin/mL). Two to 3.5 cm of PE10 were inserted into the lower abdominal aorta via the femoral artery and vena cava via the femoral vein. Both cannulas were tunneled subcutaneously to the nape and exteriorized. At the end of the surgery the surgical site was closed using surgical thread. Both cannulas were filled with heparin-saline solution (500 USP unit/mL) at the end of the procedure. Animals were then outfitted with a rodent tethering harness and miniature feed-through swivels and placed individually in metabolic cages. Animals were allowed to recover from the surgery 0.5 to 1.5

hours and resided in the metabolic cage throughout the entire experiment. After the recovery period, the venous cannula was connected to an automatic infusion pump. Conscious animals were subjected to infusion of the control solutions (10 g/dL polyOR-Hb in lactated Ringer's solution, and the same diluted to 4 g/dL in plasma) or test articles (the products of Example 2, low molecular weight (LOMW) and high molecular weight (HIMW) HES-Hb, 5.0 and 3.5 g Hb/dL in lactated Ringer's solution), respectively equivalent to 10% of total blood volume, delivered at 0.2 mL/min. Blood samples were collected 20 min after the end of infusion (time=0.33 hr post-infusion) and at time=1, 3, 6, 10, 22, 28 and 34 hours. Plasma was separated by centrifugation and stored at -80°C until analyzed by size exclusion chromatography. Total hemoglobin was calculated from background-corrected absorbances recorded at 414 nm, and plotted against time of blood collection, and plasma half-lives were derived from single exponential fits. Plasma half-lives were 5.1, 5.5, 8.9 and 15.6 hours for the 4 and 10 g/dL polyOR-Hb, and the LOMW and HIMW HES-Hb solutions, respectively.

When compared with the half-life obtained for the product of Example 7, which had a similar molecular weight distribution to that of LOMW, it appears from the limited experimental data that a longer half-life is obtained for the latter product which is derived from the more highly oxidized HES.

Example 10: In vitro stability of Hb-HES in plasma

Hb-HES prepared in Example 6 was diluted 10-fold in rat plasma and incubated at 37°C, simulating a 5-10% (vol/vol) topload administration. The mixture was analyzed by size exclusion chromatography under dissociating,

non-denaturing conditions (0.5 M MgCl<sub>2</sub> + 25 mM Tris pH 7.4), over a 49 hour period. The results are shown on Fig. 9. No low molecular weight species, indicative of product degradation, were detected during this time. High molecular weight species, eluting at the exclusion limit of the analytical column, appeared within the first hour of incubation. These species correspond to high molecular weight complexes of the modified hemoglobins and rat haptoglobin, in agreement with observations made using several other polymerized hemoglobin products incubated in plasma.

Example 11 - Stabilization of Various MW Species during Hb-HES Conjugation

Dimethylamine borane (DMB) reduction was used to terminate molecular weight changes occurring during conjugation of Hb to oxidized HES. 2.0 mL COHb (200 mg/mL in H<sub>2</sub>O) combined with 490  $\mu$ L 80 mM HEPES pH 8.1 was deoxygenated. 674 mg N<sub>2</sub> charged oxidized HES (prepared previously from HES 450/0.7, 1.10 eq periodate per calculated diol) was dissolved in 6.8 mL of degassed 80 mM HEPES pH 8.1. 950  $\mu$ L of the Hb solution was added to the oxidized HES solution, giving a final Hb:HES(450kDa) ratio of 1:1. After 3 hours, 2 mL of this reaction mixture were added to a freshly prepared solution of 152 mg N<sub>2</sub>-charged DMB (providing approximately 3 eq DMB per initial aldehyde calculated for the oxidized HES), dissolved in 1.6 mL degassed water with 350  $\mu$ L 4 M NaOAc added. A 2 mL aliquot of the Hb-HES reaction was similarly treated after 6 hours. After 22 hours, the reactions were charged with CO and dialyzed extensively vs. water over 72 hours at 4°C. MW distributions during conjugation, reduction and after dialysis were measured by size exclusion chromatography under dissociating, non-denaturing conditions (0.5 M MgCl<sub>2</sub>

+ 25 mM Tris pH 7.4). The results are shown on Figure 10, for the products subject to reduction at 3 hours, Fig. 11 for the products subject to reduction at 6 hours, and Fig. 12 for the non-reduced products. The MW distribution of products observed at 3 hours and 6 hours (both high MW conjugates) did not change significantly during 22 hours of reduction at room temperature, nor during 72 hours dialysis at 4°C. Therefore, reduction with 3 eq. DMB per initial aldehyde prevented transformation of the Hb-HES conjugate to lower MW, as seen in samples which were not reduced (Figure 10). Stabilization of high MW species was also seen when using fewer equivalents of DMB per initial aldehyde, as described in Example 3. This reduction method can be used to stabilize any MW distribution that develops during the conjugation reaction.

WHAT IS CLAIMED IS:

1. A polysaccharide-hemoglobin conjugate useful as an oxygen transporter, comprising hemoglobin covalently linked  
5 through secondary amine linkages between amino groups on the hemoglobin and residues of aldehyde groups on the polysaccharide produced by oxidative saccharide ring-opening thereof, the secondary amine linkages having been formed by reaction of said amino groups and said aldehyde  
10 groups in a first stage to form Schiff base linkages, and in a second, subsequent stage by reduction to effect stabilization, the conjugate having no detectable residual unbound hemoglobin and no detectable residual amounts of components of molecular weight higher than about 500kDa.  
15
2. The conjugate of claim 1 wherein the polysaccharide is hydroxyethyl starch or dextran
3. The conjugate of claim 2 wherein hemoglobin is  
20 human hemoglobin.
4. The conjugate of claim 3 wherein the hemoglobin is deoxyhemoglobin.
- 25 5. The conjugate of claim 3 wherein the hemoglobin is intramolecularly cross-linked.
6. The conjugate of claim 3 wherein the polysaccharide is hydroxyethyl starch of molecular weight from about 70 to  
30 about 1000 kDa.
7. The conjugate of claim 6 wherein the hydroxyethyl starch has a substitution ratio from about 0.5 to 0.7.
- 35 8. The conjugate of claim 6 having a P50 from 4 - 50 at

37°C.

9. A process of preparing a hemoglobin based oxygen carrier which comprises reacting an oxidatively ring-opened polysaccharide carrying aldehyde groups, with hemoglobin, to form a conjugate thereof, maintaining the conjugate under controlled conditions of aqueous solution with predetermined pH to effect controlled molecular weight reduction and molecular weight re-distribution of the conjugate, stabilizing the conjugate by reduction of the Schiff base linkages, between the polysaccharide and the hemoglobin to stable, secondary amine linkages, and recovering a solution of the polysaccharide-hemoglobin conjugate so formed which has no detectable unbound hemoglobin residue and no detectable product residue of molecular weight greater than about 500-600 kDa.

10. The process of claim 9 wherein the polysaccharide is dextran or hydroxyethyl starch(HES).

11. The process of claim 10 wherein the conjugate is maintained in aqueous solution under pH conditions from about 7.2 - 10, at temperatures from about 15 - 30°C to effect molecular weight reduction and molecular weight re-distribution.

12. The process of claim 11 wherein the molecular weight reduction and molecular weight redistribution is terminated at a predetermined extent by said stabilization of the conjugate by reduction of the aldehyde-amine bonds to secondary amine linkages.

13. The process of claim 12 including a single stage of reduction, to effect said stabilization and substantially simultaneously to reduce residual aldehyde groups.

14. The process of claim 12 including two stages of reduction, the first to effect said stabilization and the second to reduce the aldehyde groups.

5 15. The process of claim 13 wherein the reduction is effected with a boron-based reducing agent.

16. The process of claim 15 wherein the reducing agent is borane dimethylamine.

10

15

20

25

30

**AMENDED CLAIMS**

[received by the International Bureau on 14 September 1999 (14.09.99);  
original claims 1-16 replaced by amended claims 1-16 (3 pages)]

1. A conjugate of hemoglobin and a polysaccharide of molecular weight at least 70 kDa and selected from hydroxyethyl starch and dextran, useful as an oxygen transporter in mammalian systems, comprising hemoglobin covalently linked to the polysaccharide by means of secondary amine linkages between amine group residues on the hemoglobin and aldehyde group residues on the polysaccharide, the conjugate having no detectable unbound hemoglobin, and no detectable residual amounts of components of molecular weights higher than about 500 kDa.
2. A conjugate according to claim 1 wherein the polysaccharide is hydroxyethyl starch.
3. A hydroxyethyl starch-hemoglobin conjugate according to claim 2 having a molecular weight distribution of from about 100-200 kDa.
4. A conjugate according to claim 2 or claim 3 wherein the hemoglobin is human hemoglobin.
5. A conjugate according to claim 2, claim 3 or claim 4 wherein the hemoglobin is deoxyhemoglobin.
6. A conjugate according to any of claims 2-5 wherein the hemoglobin is intramolecularly cross-linked.



7. A conjugate according to any of claims 2-6 wherein the polysaccharide is hydroxyethyl starch of molecular weight from about 70 to about 1000 kDa.
8. A conjugate according to any of claims 2-7 wherein the hydroxyethyl starch has a substitution ratio of from about 0.5 to 0.7.
9. A conjugate according to any of claims 2-8 having a P50 from 4-50 at 37°C.
10. A process of preparing a hemoglobin based oxygen carrier which comprises reacting an oxidatively ring-opened polysaccharide carrying aldehyde groups, with hemoglobin, to form a conjugate thereof, maintaining the conjugate under controlled conditions of aqueous solution with predetermined pH to effect controlled molecular weight reduction and molecular weight re-distribution of the conjugate to predetermined ranges of values, stabilizing the conjugate, after said predetermined ranges of values have been achieved, by reduction of the Schiff base linkages between the polysaccharide and the hemoglobin to stable, secondary amine linkages, and recovering a solution of the polysaccharide-hemoglobin so formed which contains no detectable product residue of molecular weight greater than about 500-600 kDa.
11. The process of claim 10 wherein the polysaccharide is dextran or hydroxyethyl starch.

12. The process of claim 10 or claim 11 wherein the conjugate is maintained in aqueous solution under pH conditions from about 7.2-10, at temperatures from about 15-30°C, to effect molecular weight reduction and molecular weight re-distribution.
13. The process of claim 10, claim 11 or claim 12 including a single stage of reduction, to effect said stabilization and substantially simultaneously to reduce residual aldehyde groups.
14. The process of claim 13 wherein the reduction is effected with a boron-based reducing agent.
15. The process of claim 14 wherein the reducing agent is borane dimethylamine.
16. The process of claim 10, claim 11 or claim 12 including two successive stages of reduction, the first to effect said stabilization and the second to reduce residual aldehyde groups.

**STATEMENT UNDER ARTICLE 19**

The amendments made to the claims of this application are believed to clear the prior art citations located in the international search. The following remarks are intended to assist in the International preliminary examination of the substitute claims, shortly to be requested.

As regards product claims 1 through 9, they are restricted to conjugates of hemoglobin and a polysaccharide which is either hydroxyethyl starch or dextran, and has a molecular weight of at least 70 kDa. The only item of prior art demonstrating the use of hydroxyethyl starch is U.S. Patent 4,900,780 Cerny, and this reference uses a modified hemoglobin, and does not show a product free from unbound hemoglobin residue nor free from high molecular weight products.

The only reference possibly showing a product free of high molecular weight residues and suggesting a reduction in molecular weight distribution is Klett et al., and this reference starts with a relatively low molecular weight dextran (10 kDa) as compared with the minimum 70 kDa specified in substitute claim 1.

As regards the process claims, substitute claims 10-16, these all incorporate the feature of a process step of controlling molecular weight reduction and a molecular redistribution of the conjugate to predetermined values, followed by stabilization to "lock in" the achieved values. None of the references shows such a step.

1/7

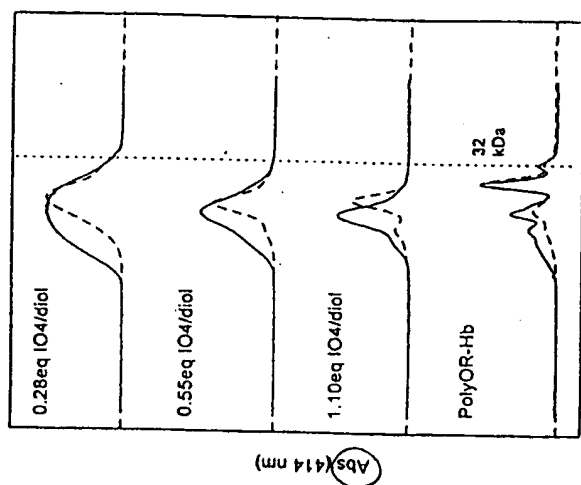


FIG. 1

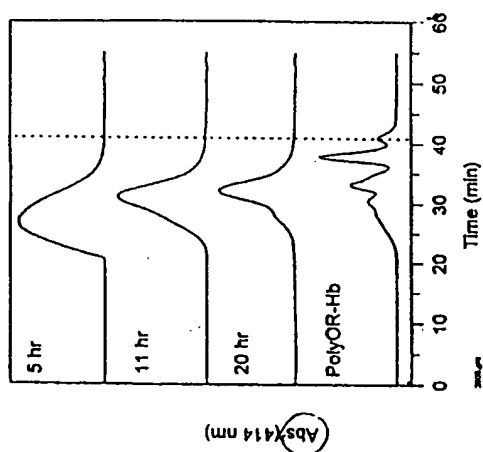


FIG. 2

↑↑

2/7

Size exclusion chromatographic analysis of  
Hb + oxidized 70 kDa HES, various time  
points in reaction.

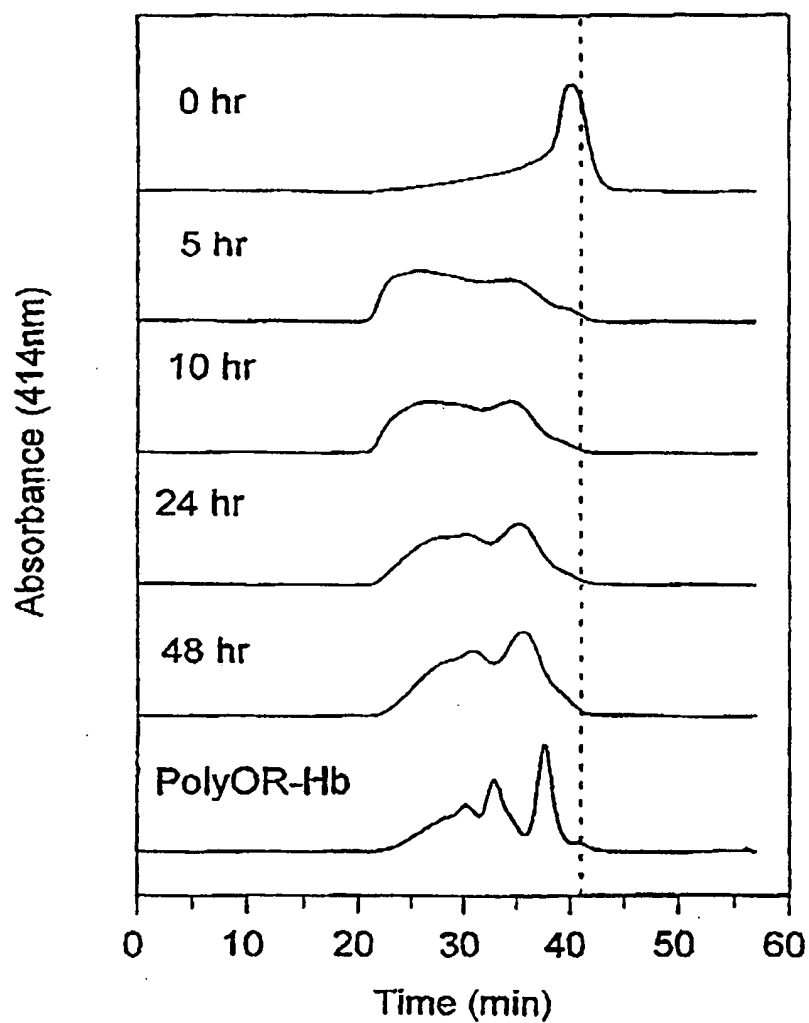


FIG. 3

3/7

Size exclusion chromatographic analysis of HIMW and LOMW Hb-HES products, compared with PolyOR-Hb

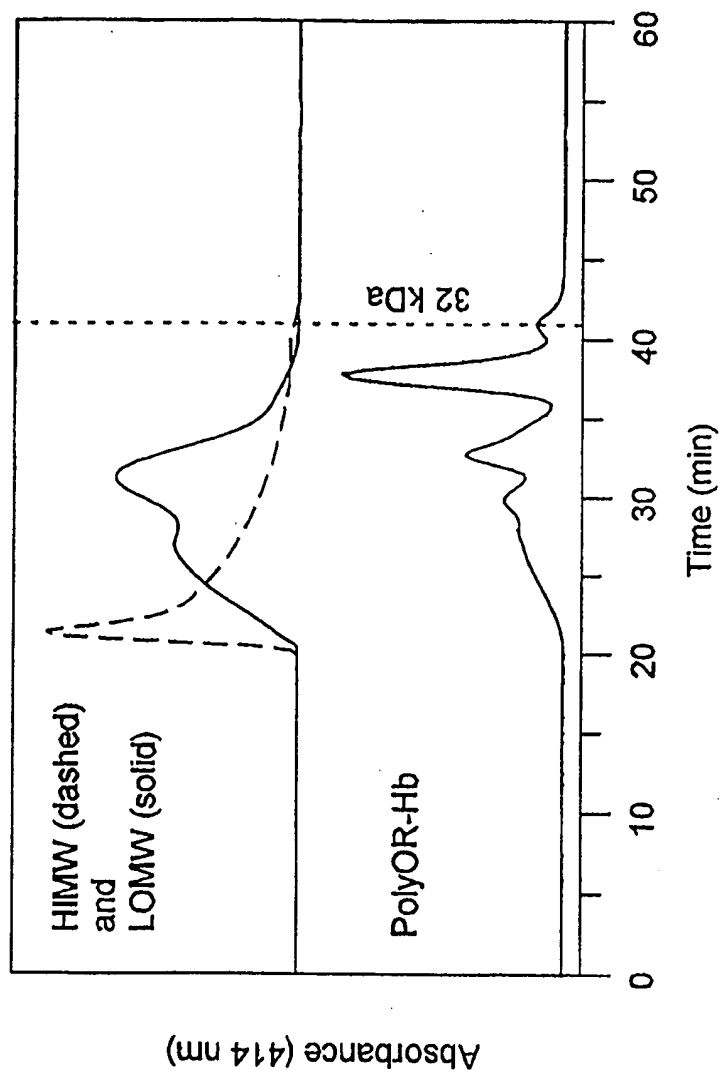


FIG. 4

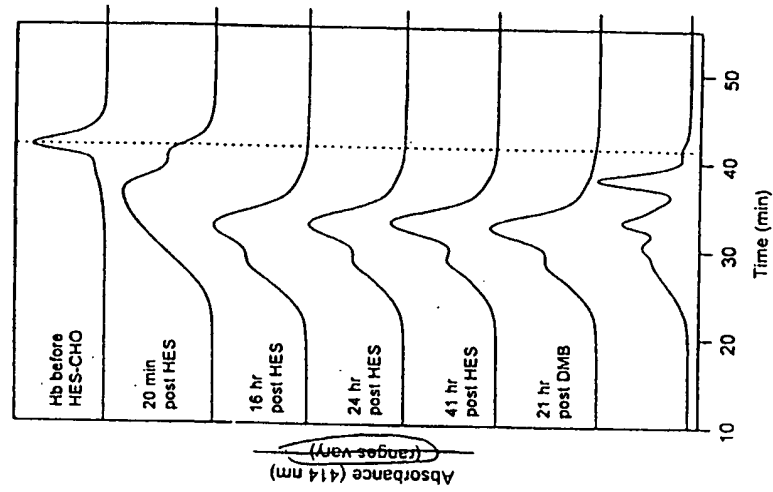


FIG. 6

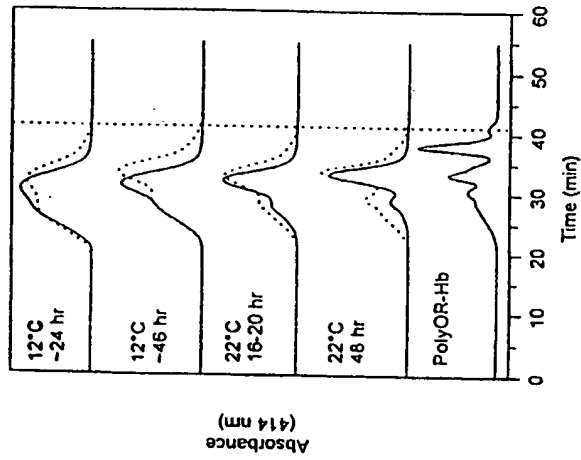


FIG. 5

## MW Distribution during conjugation of COHb with Oxidized Dextran (260 kDa)

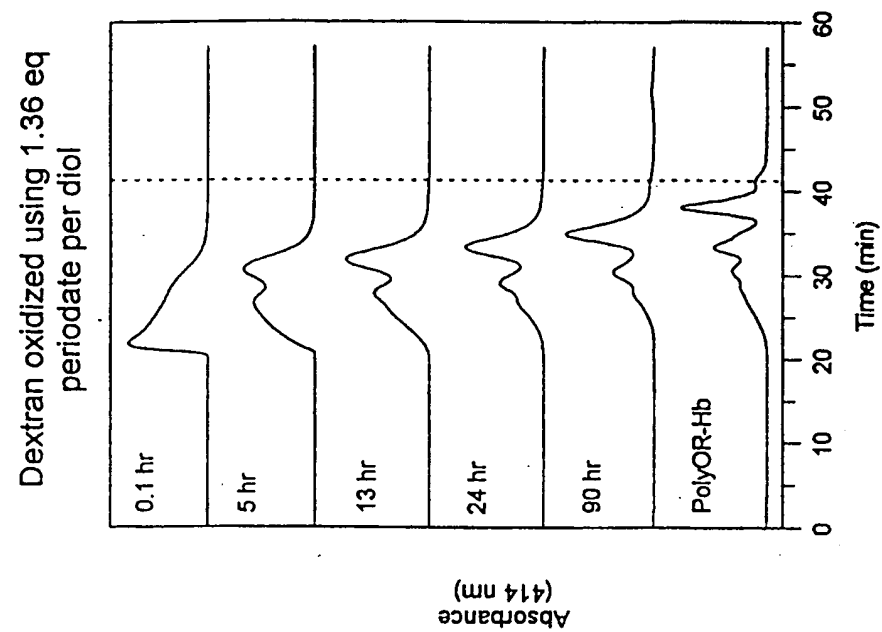


FIG. 8

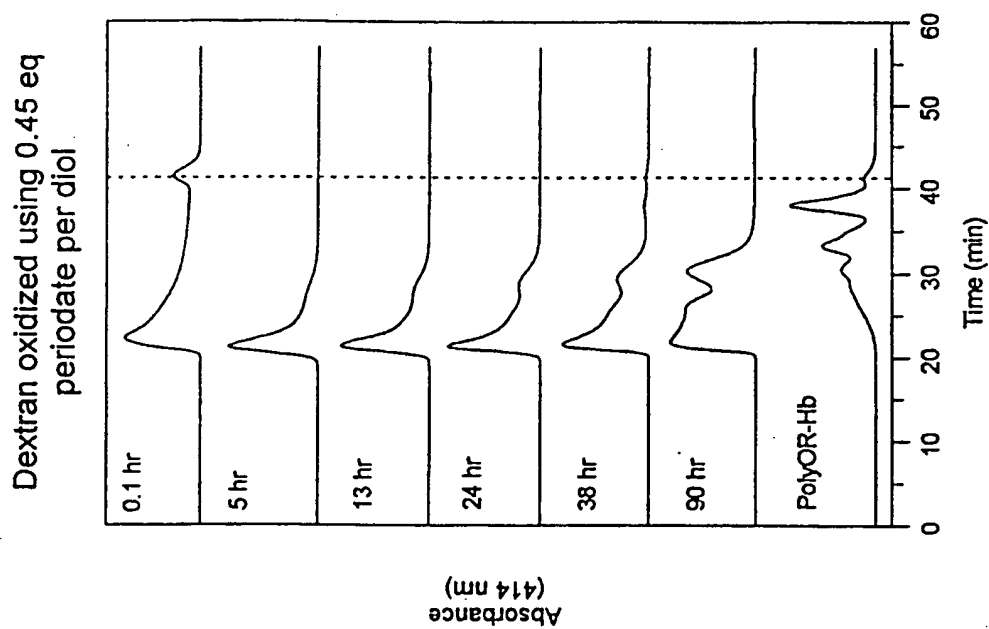


FIG. 7



## Hb-HES Stability in Rat Plasma (37°C): 10% (v/v)

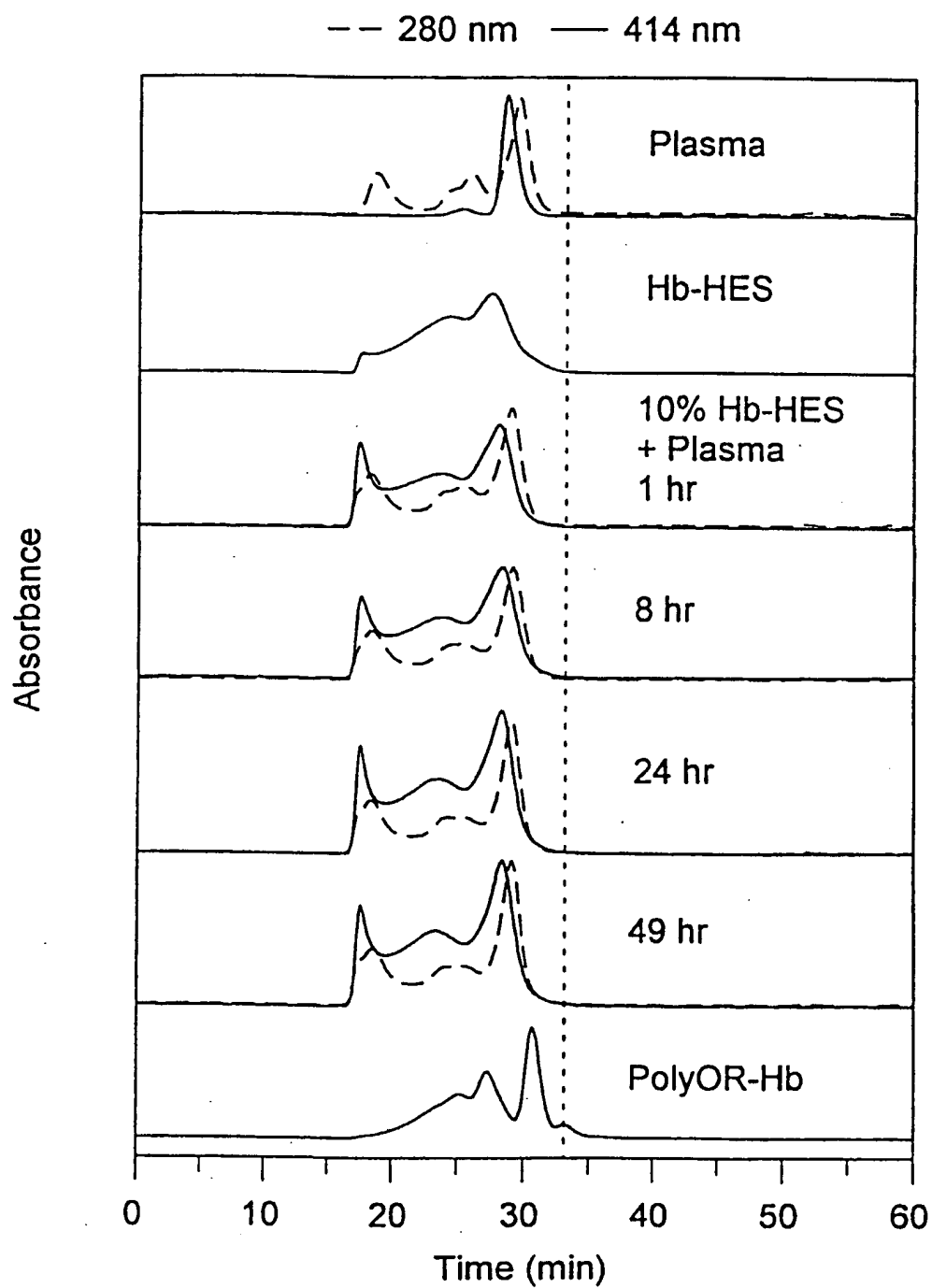


FIG. 9

Stabilization of Hb-HES MW distribution by DMB reduction.

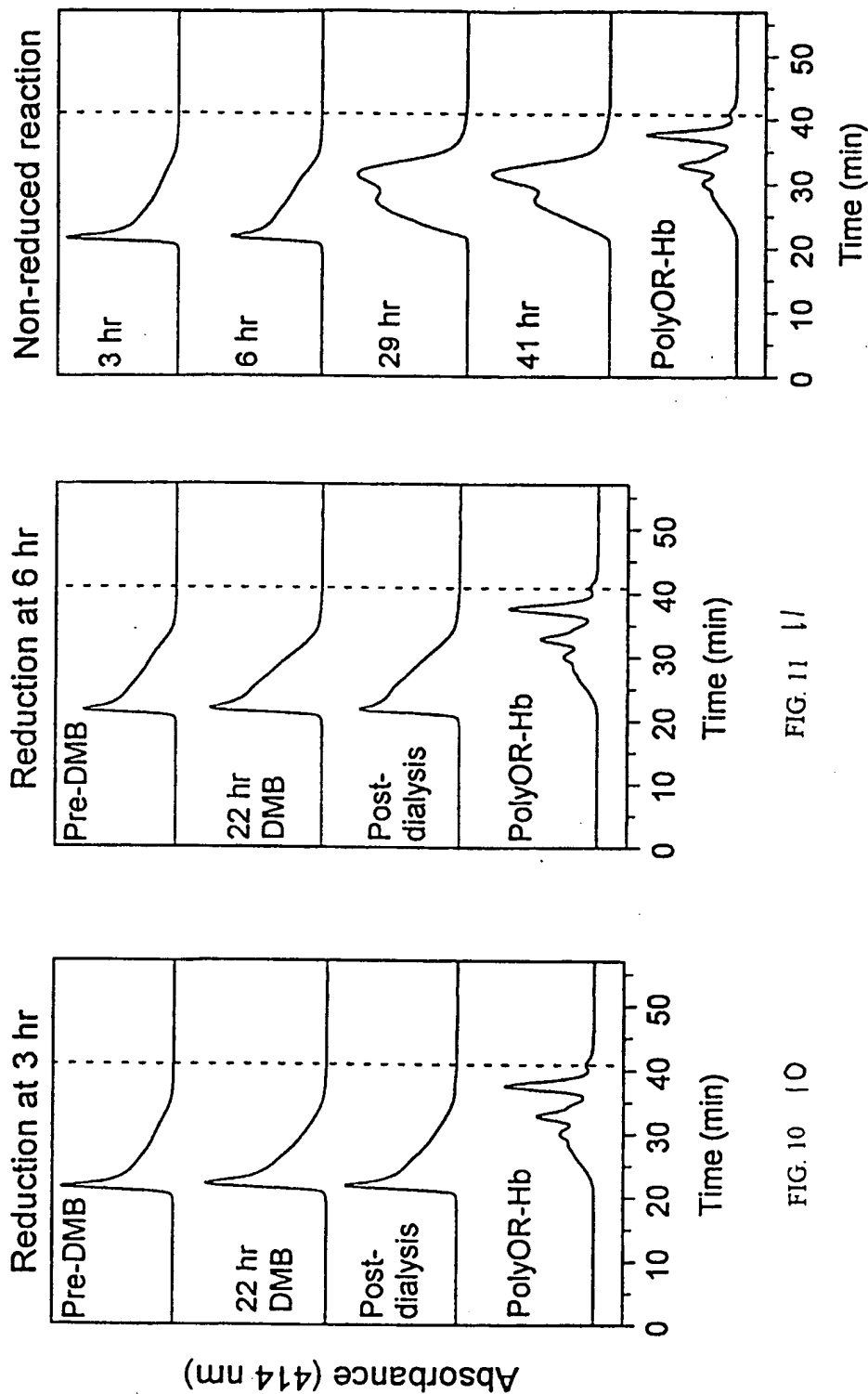


FIG. 12

FIG. 11

FIG. 10

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 99/00260

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 6 A61K47/48

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 A61K C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 900 780 A (CERNY LAWRENCE C) 13 February 1990 see examples 7-14,16 ---	1-16
X	FR 2 640 141 A (MERIEUX INST) 15 June 1990 see page 6 - page 9 ---	1-16
X	FR 2 328 478 A (WONG JEFFREY) 20 May 1977 see page 5, line 23 - line 40 see example 5 --- -/--	1-16

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

30 June 1999

Date of mailing of the international search report

15/07/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Dullaart, A

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 99/00260

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>DATABASE DISSERTATION ABSTRACTS University Microfilms International AN = 01357490, BONNEAUX, FRANCOIS: "ROLE OF ALDEHYDIC DEXTRANS IN DEVELOPING COVALENT HUMAN HEMOGLOBIN CONJUGATES TO BE USED AS INTRAVASCULAR OXYGEN-CARRIERS" XP002107868 see abstract &amp; DISSERTATION ABSTRACTS INTERNATIONAL, vol. 55, no. 02-C, 1992, page 583</p>	1-16
X	<p>CERNY, L. C. ET AL: "Mixtures of erythrocytes and acellular fluids: an in vitro evaluation" ARTIF. CELLS, BLOOD SUBSTITUTES, IMMOBILIZATION BIOTECHNOL., 1994, VOL. 22, NO. 3, PAGE(S) 633-639, XP002107860 see paragraph MATERIALS AND METHODS see figure 1 see paragraph DISCUSSION</p>	1-16
X	<p>BONNEAUX, FRANCOIS ET AL: "Fixation of various aldehydic dextrans onto human hemoglobin: study of conjugate stability" J. PROTEIN CHEM., 1995, VOL. 14, NO. 1, PAGE(S) 1-5, XP002107861 see abstract see paragraph 2.1 - paragraph 2.3 see figures 1,2 see table 1 see paragraph DISCUSSION</p>	1-16
X	<p>BONNEAUX, FRANCOIS ET AL: "Hemoglobin - dialdehyde dextran conjugates: improvement of their oxygen-binding properties with anionic groups" J. PROTEIN CHEM., 1996, VOL. 15, NO. 5, PAGE(S) 461-465, XP002107862 see abstract see page 462 see page 465</p>	1-16
X	<p>KLETT, D. ET AL: "Fixation of aldehydic dextrans onto human deoxyhemoglobin" BIOPOLYMERS, 1992, VOL. 32, NO. 5, PAGE(S) 517-22, XP002107863 see page 518 see figure 3 see page 521, right-hand column</p>	1-16

-/--

# INTERNATIONAL SEARCH REPORT

In... national Application No  
PCT/CA 99/00260

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	TAM, SIU-CHEUNG ET AL: "Soluble dextran - hemoglobin complex as a potential blood substitute" PROC. NATL. ACAD. SCI. U. S. A., 1976, VOL. 73, NO. 6, PAGE(S) 2128-31, XP002107864 see abstract see page 1871, right-hand column see figure 3 see paragraph DISCUSSION	1-16
Y	CERNY, L. C. ET AL: "A hydroxyethyl starch - hemoglobin polymer as a blood substitute" CLIN. HEMORHEOL., 1982, VOL. 2, NO. 4, PAGE(S) 355-65, XP002107865 see abstract see paragraph RESULTS AND DISCUSSION	1-16
Y	WONG, J. TZE-FEI ET AL: "Biophysical basis of hypoxic radioprotection by deoxygenated dextran - hemoglobin" INT. J. RADIAT. ONCOL., BIOL., PHYS., 1986, VOL. 12, NO. 8, PAGE(S) 1303-6, XP002107866 see abstract see table 1 see page 1306, right-hand column	1-16
Y	MAOUT, ETIENNE ET AL: "Hydroxyethyl starch conjugated to human hemoglobin for use in blood transfusion: Comparison with dextran conjugates" FRONT. BIOMED. BIOTECHNOL., 1993, VOL. 1, NO. CARBOHYDRATES AND CARBOHYDRATE POLYMERS, PAGE(S) 132-40, XP002107867 see abstract see paragraph CONCLUSION	1-16
Y	WO 91 15215 A (BIOMED FRONTIERS INC) 17 October 1991 see example 1	1-16
Y	EP 0 338 916 A (MERIEUX INST) 25 October 1989 see page 17, line 55 - page 18, line 12	1-16
Y	DE 26 16 086 A (FRESENIUS CHEM PHARM IND) 3 November 1977 see page 6 - page 7 see example	1-16

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA 99/ 00260

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.:                      and 9 in part  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:  
See FURTHER INFORMATION sheet PCT/ISA7/10
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims: it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

## INTERNATIONAL SEARCH REPORT

International Application No. PCT/CA 99 00260

FURTHER INFORMATION CONTINUED FROM PCT/SA/ 210

Claims Nos.: 1 and 9 in part

In view of the large number of compounds, which are defined by the general definition in these claims, the search had to be restricted for economic reasons. The search was limited to the compounds for which pharmacological data was given and/or the compounds mentioned in the claims, and to the general idea underlying the application (see guidelines, Chapter III, paragraph 2.3).

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 99/00260

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4900780	A	13-02-1990	NONE	
FR 2640141	A	15-06-1990	NONE	
FR 2328478	A	20-05-1977	CA 1055932 A	05-06-1979
			AU 510466 B	26-06-1980
			AU 1885276 A	27-04-1978
			BE 847462 A	14-02-1977
			DE 2646854 A	05-05-1977
			GB 1549246 A	01-08-1979
			JP 1297893 C	20-01-1986
			JP 52051016 A	23-04-1977
			JP 60021124 B	25-05-1985
			NL 7611580 A, B,	26-04-1977
			SE 429404 B	05-09-1983
			SE 7611797 A	23-04-1977
			US 4064118 A	20-12-1977
WO 9115215	A	17-10-1991	CA 2084073 A	01-10-1991
			AU 654652 B	17-11-1991
			EP 0523037 A	20-01-1993
			US 5416078 A	16-05-1995
EP 0338916	A	25-10-1989	FR 2630329 A	27-10-1989
			AT 77753 T	15-07-1992
			ES 2043054 T	16-12-1993
			GR 3005220 T	24-05-1993
			JP 2042023 A	13-02-1990
			US 5110909 A	05-05-1992
DE 2616086	A	03-11-1977	NONE	